Pol. J. Environ. Stud. Vol. 23, No. 3 (2014), 943-948

Short Communication

Investigations of Gravel Road Dust Minimization by Applying Different Salt Solutions

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Received: 4 November 2013
Accepted: 28 February 2014

Abstract

Dust on gravel roads is reduced through the application of various dust minimization materials, most frequently calcium chloride. However, global efforts have been intensified to find new effective materials that cause the least damage to the environmental. One of them is Safecote, a new patented product. In 2008 measurements were performed on the gravel road Jusevičiai-Būdvietis-Derviniai, which was treated with calcium chloride. Experiments of particulate matter concentrations in the air, when gravel road pavement was treated with a mixture of calcium chloride and Safecote, were carried out in the summer of the same year. As the findings of the experimental investigation of particulate matter concentrations in the air show, the concentration of particulate matter on the gravel road treated with calcium chloride alone reached, on average, 1.90 mg/m^3, while on that treated with the mixture was 0.40 mg/m^3.

Keywords: calcium chloride, Safecote, gravel road, dust minimization, experimental investigation, particulate matter (PM)

Introduction

Lithuania has a dense network of national roads. The total length of Lithuania's road network currently exceeds 21,000 km, with gravel (unpaved) roads accounting for 36% of this total (i.e. around 7,600 km) [1].

In the dry period of the year the environment is badly polluted with dust caused by vehicles driving along gravel roads. According to data of 1 January 2013 [2], the length of significant roads with gravel pavement constitutes 7,604.084 km in Lithuania. Environmental pollution with dust on the gravel roads on which traffic intensity ranges from several dozen to several hundred vehicles per day amounts to hundreds of thousands of tons [3]. Dust is dangerous to humans and can cause various allergies and diseases [4-6]. When raised, dust may cover crops and grass vegetation growing by gravel roads, which may result in the suppression of growth due to blocked plant pores [4, 7]. Dust reduces plant yield 15-30% [1] and the quality of agricultural products [8].

Recently, the minimization of dust on gravel roads has gained significance while improving the maintenance of the Lithuanian national roads. Lithuania lacks financial and technical capacities to apply asphalt surfacing on all gravel roads. Furthermore, huge investments in some gravel roads do not always pay back due to low traffic intensity [9]. Around 2 cm of paving "dusts away" from gravel roads every year. Consequently, in a year roads lose up to 1.7 million tones of gravel that has to be restored, while these are enormous losses for the state [10]. One of the options to minimize dust on gravel roads is to reduce driving speed. Taking account of the total length of gravel roads in the country, the average intensity and composition of traffic, and the condition of gravel roads, Laurinavičius and Žilionienė [11] calculated that the time loss of labour on gravel roads resulting from the reduced speed limit amounted to up to LTL 13.0 million per year. Should they take account

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of vehicle depreciation, environmental pollution with dust, vehicle emissions, and traffic accidents, this figure could be much bigger.

Gravel road dust can be minimized (without applying asphalt, concrete, or bituminous emulsion for surfacing) by applying agents that minimize gravel goad dust such as calcium lignosulphonate, calcium chloride, or asphalt emulsion [7, 12]. Dust minimization materials are but one of a wide variety of techniques [13, 14].

Recent efforts have been made to find new environmentally friendly materials that would effectively reduce gravel road dust. One such material is the commercial solution Safecote.

Safecote is a by-product derived in the sugar production process that is used in a mixture with salts. Safecote boasts powerful corrosion inhibition properties and is friendly to the environment [15]. Thus, it is a natural agricultural by-product that is biodegradable (produced from renewable natural sources); biologically and chemically stable; inhibits salts from leakage (which reduces the necessity to use ferrocyanides); reduces the application of salts that contain inorganic chlorides; calculation of flow dilution coefficients was tested according to the Technology Readiness Level; and Safecote does not contain chlorides [15].

Safecote's unique properties allow it to – even when mixed at 3% to one ton of rock salt – provide a faster response to snow and ice control, with road safety benefit [15]. The effectiveness of Safecote in minimizing gravel road dust is not yet known. As a snow and ice control agent, Safecote is used together with salts, and the solution therefore is also mixed with salts for the minimization of gravel road dust.

Salts are widely applied for gravel road dust minimization. According to results obtained during the investigations of dust minimization by applying calcium chloride carried out in Lithuania, the effectiveness of calcium chloride in minimizing dust ranged from 10 to 45%, depending on a variety of conditions [16-18]. Unfortunately, calcium chloride harms the environment. Therefore, it is necessary to find a way to minimize dust by making the least possible damage to vegetation along gravel roads.

The aim of our research is to compare particulate matter concentrations that were recorded while using only calcium chloride and a calcium chloride and Safecote mixture for dust minimization.

Methodology of Research

Determination of Fractional Composition of Gravel Road Pavement

The aim of determination is to compare the fractional composition of the pavement of gravel roads treated only with calcium chloride and with a Safecote and calcium chloride mixture.

A 1 kg sample of gravel of each pavement concerned was taken. Samples were sieved with the analytical sieve shaker AS200 Digital at 70 shaking amplitude (70 shake times in 1 min.) for 3 minutes. The gravel fractions were as follows: >5 mm, 5-4 mm, 4-2.5 mm, 2.5-2 mm, 2-1.6 mm, 1.6-1 mm, 1-0.9 mm, 0.9-0.6 mm, 0.6-0.4 mm, 0.4-0.3 mm, 0.3-0.2 mm, 0.2-0.1 mm, 0.1-0.05 mm, and <0.05 mm. The size of gravel fractions was selected not according to the standard in order to determine the share of a minor fraction in road pavement.

Determination of Air Conditions

The aim of research is to compare ambient air conditions (air temperature, humidity, wind speed, wind direction) in the places of investigations.

All meteorological parameters were observed three days before the planned start of an investigation of particulate matter concentration in the air. It was not raining and air temperature was not below 18ºC for three days in a row before starting measurements. 18ºC temperature was chosen because average temperature during June in Lithuania for the past 10 years was about 18ºC. Air temperature, humidity, and wind speed were measured with a TESTO-400 microclimate analyzer. The analyzer makes measurements within the limits of (–20...+70) C, (0...100)%, and (0...10) m/s, and the analyzer's measurement errors are ±0.5ºC, ±2%, ±0.03 m/s. The direction of the wind was determined visually. A more precise determination is described by Zaveckytė (Bradulienė) and Vasarevičius [19].

Measurement of Particulate Matter Concentration in the Air

The aim of our research is to compare particulate matter (PM) concentration in the air by forming the transverse profiles of the roadsides of gravel roads treated with dust minimization materials (calcium chloride alone, and a Safecote and calcium chloride mixture).

Measurements of dust were carried out while standing downwind and forming transverse profiles in three measurement points: at 0 m, 1 m, and 2 m distance from the road. Such distances were selected with the aim of identifying the particulate matter concentration, which may precipitate on the vegetation growing by the roadside. Measurements were carried out on gravel roads treated with calcium chloride alone and with a Safecote and calcium chloride mixture. Measurements were also carried out in gravel road sections not treated with any dust minimization solutions (control measurements).

Measurements of PM concentrations in the air were made with a MicroDust pro dust concentration analyzer. During investigations the measurement limit and error are subject to the analyzer's first level, i. e. the measurement limit ranges from 0.001 to 2.5 mg/m^3, error is ±0.001 mg/m^3.

During PM concentration measurements the analyzer was held at a height of 1 m from the base.

Dust on the gravel road was generated by a vehicle driving at a speed of about 50 km/h (i. e. (50±5) km/h). This is the maximum speed allowed on gravel roads in Lithuanian settlements.

A more precise determination is described in the article by Zaveckytė (Bradulienė) and Vasarevičius [19].

The gravel road treated with calcium chloride stretches in the southwest of Lithuania.

Calcium chloride was inserted into the top layer of gravel road pavement in the following manner: gravel road paving was crushed with a motor grader and afterward calcium chloride was applied to it with a salt spreader. Chloride application was done twice. Half of the salt amount (1.5 tons) was used during the first application. The top layer of the gravel road pavement was mixed with the sprayed calcium chloride. Afterward, the remaining amount of calcium chloride (1.5 tons) was applied to the top layer of the gravel road with the salt spreader. The top layer of the gravel road pavement was mixed with the sprayed calcium chloride for the second time. Afterward water was sprayed over the top layer of the pavement. Finally, the top layer of the gravel road pavement was rolled (a road roller weighs around 12 tons).

The amount of calcium chloride totaled 400 g/m^2. Water amount was equal to 3 t/km. The labor costs of the equipment used amounted to around LTL 10,000 per kilometer.

The gravel road section treated with a Safecote and calcium chloride mixture is in southeastern Lithuania.

The mixture was applied on gravel road pavement as follows: first, solutions of three types were prepared. Half of the amount of one prepared solution was sprayed over the gravel road pavement with a manual sprayer (Fig. 1). The remaining amount of the same type solution was sprayed after 5 minutes.

The ratio of the mixture's components is 1:1 of a Safecote and calcium chloride solution. The concentrations of the prepared mixtures are as follows: 10% of Safecote and 36.5% of $CaCl_2$, 20% of Safecote and 36.5% of $CaCl_2$, and 30% of Safecote and 36.5% of $CaCl_2$.

A more precise description of mixture preparation is presented by Bradulienė and Vasarevičiaus [20].

Gravel Roads under Investigation

The road Jusevičiai-Būdvietis-Derviniai is of regional significance (No. 2608). Its length is 21.57 km. The road is maintained by the state enterprise Alytaus regiono keliai.

Fig. 1. Sprinkling the mixture using a handy sprayer.

To minimize dust, the 13.25-13.85 km pavement section of this road was again treated with calcium chloride ($CaCl_2$) on April 14. Dust was measured by organizing three expeditions. The first was carried out one month and a week after the road pavement was treated with calcium chloride. The second took place two months and two weeks after road pavement treatment with calcium chloride. The third was organized after five months from road pavement treatment with $CaCl_2$.

The gravel road treated with different mixtures is near Vilnius Gediminas Technical University. Mixtures were sprayed over the gravel road. 10 measurements were made on rainless days. This experiment continued for around two months.

Results and Discussion

Results of Fractional Composition of Gravel Road Pavement

The composition of gravel fractions was obtained by weighing 1 kg of gravel from a road pavement surface. Fig. 2 shows a percentage composition of gravel taken from the pavement of two gravel roads concerned.

As Fig. 2a shows, the largest fraction, 5 mm, constitutes the major part (21.79%), while a gravel fraction with fraction size <0.05 mm accounts for the smallest share (0.55%) of the pavement of the gravel road Jusevičiai-Būdvietis-Derviniai treated with calcium chloride. Dust is mainly generated by minor particles of road pavement that remain suspended in the air and are transferred by the wind. The diameter of such particles is around 0.1 mm and below. These particles, according to mass, account for around 3% in road pavement.

As Fig. 2b shows, a 2.5-2 mm fraction constitutes the biggest share (14.95%) in the pavement of the gravel road section concerned, while particles smaller than 0.05 mm makes the least share (1.44%) in it. Particles of 4.0-2.5 mm (13.16%) and 1.6-1.0 mm (12.24%) account for more than 10%. The share from 5% to 10% consists of particles with 5-4 mm diameter (5.43%), 0-1.6 mm (9.17%), 0.9-0.6 mm (6.44%), 0.6-0.4 mm (7.47%), 0.3-0.2 mm (5.19%), 0.2-0.1 mm (5.45%), and above 5 mm (9.62%). The remaining fractions of particles account for less than 5% of mass in the total volume.

Thus, particles smaller than 1 mm account for 49.64% in the pavement of gravel road treated with $CaCl_2$, and 35.43% in the pavement of gravel road treated with a $CaCl_2$ and solution Safecote mixture. The least difference, a mere 0.19%, was in fraction sized 1-0.9 mm in both pavements. The biggest difference, 12.17%, was in the measured fraction of >5 mm.

Determination of Air Conditions

Temperature, air humidity, and wind speed were measured with the instrument TESTO-400, while the direction of wind was determined visually. Wind direction was perpendicular to the road during investigation. The average values of air condition measurement results are presented in Fig. 3.

As Fig. 3 shows, the values of air humidity and wind speed on the gravel roads treated with calcium chloride alone are higher compared to the experimental section, which was treated with a calcium chloride and Safecote solution mixture, in the meantime the value of temperature, on the contrary, was lower. Compared to the temperature recorded in the experimental section, the average temperature was by 1.42ºC lower when measuring dust on the gravel road treated with calcium chloride alone (i.e. relative measurement error is 6.56%). Air humidity differed by 10.74% (relative error equal to 18.40%), while the wind speed differed by 0.12 m/s (relative error equal to 6.46%).

As the average values of air conditions did not differ more than 20%, it can be assumed that air conditions were the same during the investigations.

Measurement of Particulate Matter Concentration in the Air

As mentioned in the methodology, particulate matter concentration in one section was measured right next to the roadside, at a distance of 1 and 2 m from it when a vehicle was driving at the same speed (about 50 km/h).

According to the Lithuanian hygiene norm (HN 35:2007) [21], the maximum available single-time concentration of particulate matter in the air of the living environment is 0.5 mg/m^3.

For each suppressant solution the PM concentration data were averaged, and the results are presented in Fig. 4.

As the presented results show (Fig. 4), lower values of PM concentrations were obtained upon using the mixtures of calcium chloride and Safecote than when applying calcium chloride alone for gravel road treatment. The PM concentration of the control sections was higher in the section investigated, as the fractional composition of the pavement is finer. A comparison of the obtained PM concentration values with the regulatory value shows that the regulatory value is exceeded by 3.8 times when applying $CaCl_2$, in the meantime upon using mixtures with the solution Safecote the regulatory value is exceeded (by 1.2 times) only at a Safecote concentration of 10%. When the concentration of Safecote in the solution is higher, the regulatory value is not exceeded. Where dust on gravel roads is minimized by mixing calcium chloride with the solution, Safecote air pollution with particulate matter decreases by 3.17 times (at Safecote con-

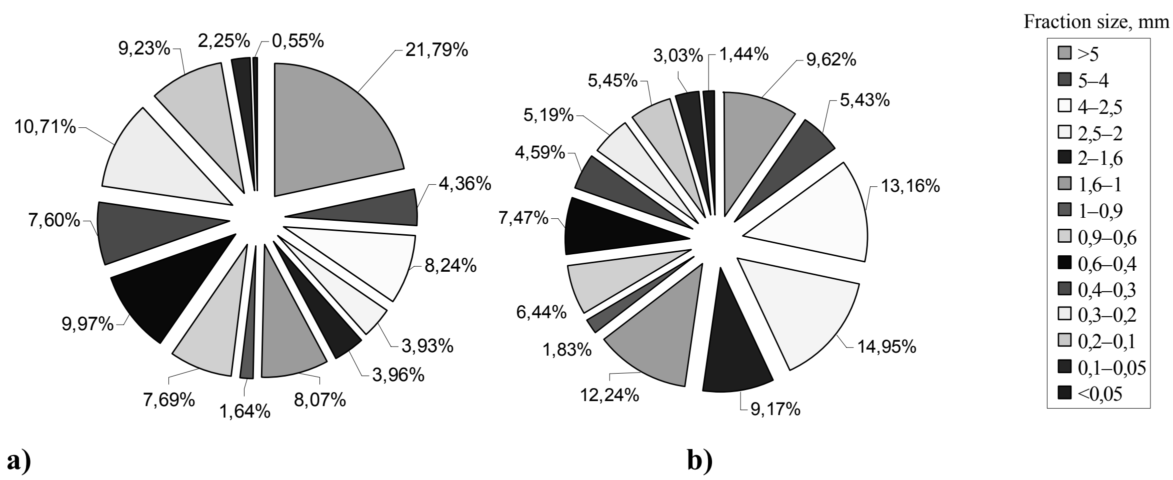

Fig. 2. Percentage compositions of gravel from road treated with: a) calcium chloride, b) mixture of calcium chloride with solution "Safecote."

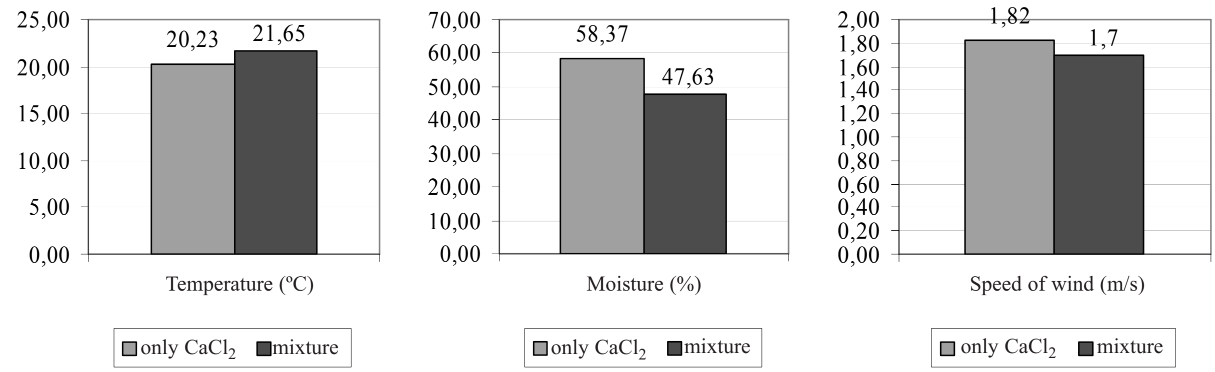

Fig. 3. The average values of air condition measurement results on gravel roads treated with calcium chloride alone and with a calcium chloride and Safecote solution mixture.

centration of 10%), 5.14 times (at Safecote concentration of 20%), and 8.64 times (at Safecote concentration of 30%).

Results of the averaged research data according to the distance from the carriageway (excluding results obtained in the control section) are presented in Fig. 5.

As Fig. 5 shows, the PM concentration on the roadside exceeds the regulatory value (by 5 times upon using $CaCl_2$, and 1.38 times when using mixtures). At a distance of 1 m from the roadside the PM concentration is lower, but upon using $CaCl_2$ the regulatory value is exceeded by 3.74 times, while upon applying mixtures with Safecote the regulatory value is not exceeded (it is lower by 1.09 times). At a distance of 2 m from the roadside the PM concentration on the roadside fell by approximately 2 times when applying both $CaCl_2$ and mixtures with Safecote. A comparison of the obtained values with the regulatory value shows that when applying $CaCl_2$ for road dust minimization the regulatory value is still exceeded (2.64 times), while upon using mixtures with Safecote the regulatory value is not exceeded (1.72 times lower).

With distance from the road increasing, the values of PM concentrations are decreasing as the blows of the wind generated by a driving vehicle scattered the major part of dust at the ground level and right next to the road and therefore lower concentrations got into the analyzer as it was held not right next to the road but while standing at some distance from the road.

Conclusions

1. When using different dust minimization materials at any distance from the road the dependence of the decreasing PM concentrations in the air on the concentration of solution was determined. Investigations have found a linear relationship.

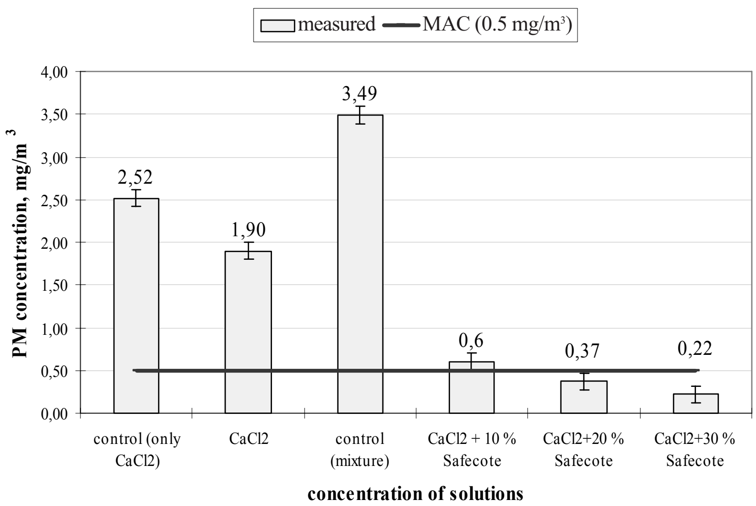

Fig. 4. Decrease of PM concentrations, then results are averaged according to the concentration of a solution (MAC – maximum available concentration).

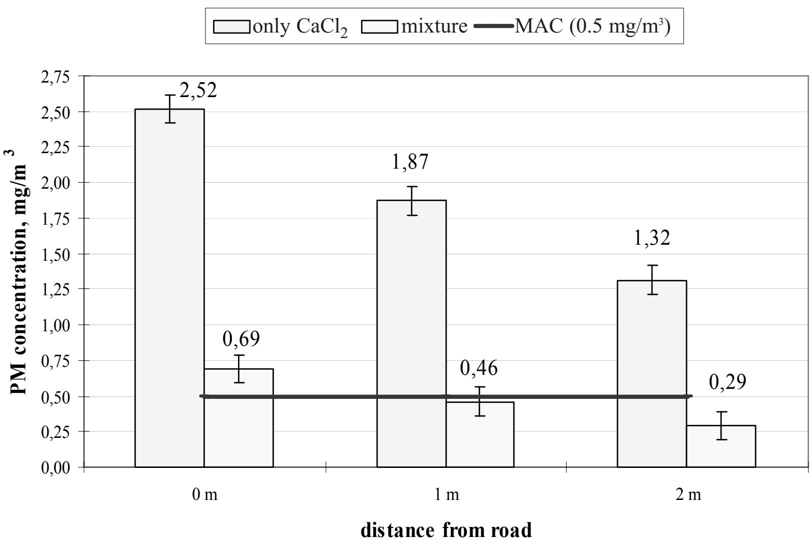

Fig. 5. Decrease of PM concentrations, then results are averaged according to the distance from the carriageway (MAC – maximum available concentration).

2. Taking account of the distance from the carriageway in the case of calcium chloride application for dust minimization the permissible norm was exceeded, while upon using a Safecote and $CaCl_2$ mixture it was exceeded only once (right next to the carriageway).
3. On the basis of the obtained results it can be stated that upon mixing calcium chloride, used for gravel road dust minimization, with the solution Safecote, air pollution with particulate matter decreases by 3.17 times (when Safecote concentration constitutes 10%) and by up to 8.64 times (when Safecote concentration is 30%).
4. Application of the mixtures of calcium chloride and Safecote solution for road dust minimization will reduce the release of dust to the ambient air and less dust will precipitate on roadside vegetation.

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